

AFRL-IF-RS-TR-2005-4
Final Technical Report
January 2005



POLYMER WAVEGUIDES FOR QUANTUM INFORMATION

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 074-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE JANUARY 2005	3. REPORT TYPE AND DATES COVERED Final Sep 03- Dec 03	
4. TITLE AND SUBTITLE POLYMER WAVEGUIDES FOR QUANTUM INFORMATION			5. FUNDING NUMBERS C - F30602-03-1-0180 PE - N/A PR - 558B TA - II WU - RS	
6. AUTHOR(S) Kamala Mahanta				
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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory/IFGC 525 Brooks Road Rome New York 13441-4505			10. SPONSORING / MONITORING AGENCY REPORT NUMBER AFRL-IF-RS-TR-2005-4	
11. SUPPLEMENTARY NOTES AFRL Project Engineer: Donald J. Nicholson/IFGC/(315) 330-7437/ Donald.Nicholson@rl.af.mil				
12a. DISTRIBUTION / AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.				12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 Words) Electro-optic materials have shown great potential for improving the performance of waveguided communication systems for use in quantum information processing (cryptography, communication, computing, etc.) where the transmission of a single photon or a very small amount of light plays a critical role in establishing the quantum nature of the process. These materials offer significant advantages over inorganic materials such as LiNbO3 or compound semiconductors due to their large EO-coefficients, low dielectric constants with negligible dispersion from DC to optical frequencies and simplicity of processing. EO polymer materials have been engineered to have improved linear and nonlinear properties, thermal stability, and a controlled poling induced optic axis for a better control of the refractive index. The research conducted with this extension grant has enabled the preparation for the design, fabrication and testing of slab waveguides made of EO polymer and covers the initial phase of installation, testing and use of the spin coating system to make a few simple slabs with the anticipation of testing those for coupling and other processes.				
14. SUBJECT TERMS Quantum Key Distribution			15. NUMBER OF PAGES 10	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	
NSN 7540-01-280-5500			Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. Z39-18 298-102	

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Introduction

Overall Objective: To build and demonstrate thin-film realizations of Mach-Zehnder interferometers for use in single-photon quantum communication systems.

The Scope of the research for this grant: This research is the initial phase of the design and fabrication of polymer waveguides for use in quantum communication systems and has involved the installation, testing and use of the spin coating system.

Task/Technical Requirements:

1. Investigate, design and fabricate polymer waveguides.
2. In collaboration with AFRL/SN, measure such properties of the experimental waveguides as attenuation, scattering loss, dispersion.
3. Final Report.

As stated in the scope, only task #1 could be addressed during the tenure of the grant, although, at the time of submitting the proposal it was hoped that if all went well, there might be enough time to cover task#2. The Department of Physics and Astronomy has yet to have a technician approved by the administration. So a technician from the facilities department had to be requested for help, who was only sporadically available due to his other commitments. Consequently, the installation and testing of the spin coater dragged beyond the duration of the grant. Even at this point we are struggling with the dispensing unit to get it running properly. Another hindering factor was the non-availability of the materials we had selected from the literature and finding vendors to give us an electro-optic material we could test. The entire process turned out to be very time and effort consuming. However, the research is continuing with a year long fellowship starting on June 1, 2004, which has been enabled by this extension grant.

Summary of accomplished tasks

During the time assigned to this extension project,

1. We continued to investigate electro-optic polymer materials in terms of suitability and availability in anticipation of a comparative study of the materials through spin coating and relevant testing. Some of the findings are reported below.
2. The assembly and installation of the spin coating system was accomplished and several dry runs using a variety of recipes and steps were carried out following instructions given in the manual as mentioned below. However, problems were encountered with the dispensing unit which may have to be returned to the vendors for checking/repair/replacement as necessary. Currently the material is being checked for the right viscosity.

3. The fabrication of the slab waveguides and the testing of their properties using the facilities available with AFRL/SN as mentioned in the tasks above are yet to be accomplished due to the problems encountered with the dispensing unit. We are planning to use a Prism Coupler to couple the EM-waves of communications wavelength (starting with 800nm and then extending to the 1300-1500nm range) to the waveguide we make. We also intend to investigate the transmission of highly attenuated signals mimicking the single photon, which in turn would lead us to transmitting single photons generated by parametric down conversion. With this objective in mind, the design fundamentals for slab waveguides were examined (Ref 3) to guide the future steps of the research.

4. A significant outcome of this extension grant has been the award of a year-long senior research associateship of the National Academy of Sciences administered by the NRC/AFOSR, which will enable us to continue this research in the year 2004-2005.

Electro-optic Polymers

Electro-optic polymers (Ref 1, 2) continue to hold the promise of low-cost, high-performance devices, although in the reliability front polymer optic devices are likely to have to struggle for acceptance. Research is very much warranted in light of the fact that despite their questionability in high-performance and high-reliability, in some niche applications they may be the only option. Polymers could outperform rival technologies in cases such as optical waveguide switches and modulators, which require a fusion of lower cost and higher performance.

Two effects, important for the functioning of communication devices, namely, thermo-optic and electro-optic effects must be mentioned since those decide the use of the material. While larger changes in the refractive index with temperature (dn/dT) is a disadvantage for temperature sensitive polymer devices such as directional couplers and interferometers, the large thermo-optic co-efficient enable switches that operate at low switching power and are insensitive to ambient temperature fluctuations so as to maintain a stable operating condition. This is helped further by the low thermal conductivity of polymers.

Electro-optic effects are important for achieving faster data transmission which means packing more wavelengths per fiber (as in wave-length division multiplexing) as well as running each wavelength at a higher bit rate. EO polymer modulators have exhibited better characteristics for faster data transmission due to the low dielectric constants (of the order 3) of polymers which allows velocity matching (equalization of the speeds of optical and microwave signals in a traveling microwave design), which is not available with any other electro-optic material. Polymer modulators have lower driving voltage and power requirements.

With the Mach-Zehnder modulator in mind, we are likely to concentrate on the refractive index manipulation using electric field poling, and the determination of the electro-optic co-efficient of the materials we select to layer following the design criteria (such as Kim et al).

It is worthwhile at this point to summarize some of the properties of electro-optic polymers since they have become an important class of nonlinear optical materials (Ref 2).

Properties of electro-optic polymers include optical, structural and mechanical characterization (Ref 2). The optical benefits are large non-resonant non-linearity, low switching energy, sub-picosecond response times, broadband transparency, high optical damage threshold and low absorption while structural and mechanical properties enable the benefits of low cost materials, engineering at the molecular level, integrated optics, room temperature operation, chemical stability and ease of processing and synthesis modifications along with resistance to radiation, heat and shock.

Importance of Electric Field Poling

Polymer materials reach their full potential only when they are made noncentrosymmetric which means that the isotropic structure of the material must be broken. Electric field poling applied to a polymer with nonlinear optical active moieties enables this noncentrosymmetry by aligning the moieties (Ref 1). In the absence of an electric field, the polymer chains in the polymer film between the poling electrodes have the dipolar molecules attached as side groups without any alignment. However, when the material is heated, the application of an electric field results in alignment of the side groups and, cooling it with the electric field on freezes that alignment and the material becomes an electro-optic polymer.

Poled polymers tend to have extraordinary electro-optic coefficients (up to 100pm/V exhibited), which being inversely device drive voltage, is likely to enable subvolt operation and high bandwidth.

This noncentrosymmetric state is, however, difficult to maintain since it tends to decay when the poling field is turned off especially at higher temperatures where future devices are expected to function.

Our process

We searched the literature for a suitable material and prepared a list of materials to look for. However, vendors were not readily available to supply those materials. The search for an electro-optic material for just the slabs has been rather time consuming. Finally two companies were found who have provided us with materials we can spincoat. The

PD George Company has supplied EPOXY E347 which we are trying to spin coat on to a silicon substrate. The other company is Lucite International, Inc. who has given us the specs for ELVACITE® 2051, an acrylic resin. This material has offered the potential for adding chromophores for electric field poling to create the noncentrosymmetry we need in the material.

We have the high vacuum system with a precision coatings monitor to make the electrodes on the two sides of the spin coated slab by thermal evaporation. We are anticipating that with a proper material in hand we will be able to pole the waveguide.

The assembly and installation of the spin coating system

Our spin coating system consists of the following Specialty Coatings Systems supplied by Cookson Electronics Equipment:

1. Model G3P-8 Desk-Top Precision Spin Coating System
2. D-6004 Coating Dispensing System
3. Hot Plate Model 1000-1

All three have been installed and connected. As stated above, the spin coater has been dry-run on a variety of recipes and steps and the dispensing unit is being sorted out at this point.

Some design fundamentals for slab waveguides

As stated in the Statement of Work submitted in response to the BAA for the proposal, this research effort supplements a DARPA program on Quantum Information Science and Technology (QuIST) intended to demonstrate advances required for practical use of quantum logic and information in computing, communications, and other applications. We are focusing on a Mach-Zehnder modulator as part of a Single Photon Quantum Communication System and gathering information on the design fundamentals from papers such as “Design and Fabrication of Electro-optic Polymer Waveguide Devices” by Kim et al (Ref 3).

In a typical triple layer stacked electro-optic modulator, with a cross sectional geometry shown below, the selection of the buffer layers becomes an important issue, once the guiding material is selected. An analysis will be necessary to determine the thickness of the guiding, lower and upper buffer layers.

The guiding layer thickness is to be calculated for the single mode operation of the communication channel layer. The Effective Index Method has been referred to for calculation of the dispersion relation for various material systems at the 1.3 μ m wavelength.

The thickness of the buffer layers decides the modulation voltage since it is inversely proportional to the total thickness of the waveguide, and the optical loss due to the metal electrodes, which is closely dependent on the guiding layer because the optical power confined in the guiding layer depends on its thickness. As shown by Kim et al, a relationship between the total thickness and the guiding layer thickness can be established for lower electrode associated loss (less than 0.1dB/cm in their case) with different refractive indices for one buffer layer, keeping the refractive index of the other buffer layer fixed. They have shown data for symmetric waveguides (same refractive index for both buffers). Modulation Efficiency ($\Delta N/\Delta n$), Figure of Merit ($\Delta N/\Delta n$)/ d_{tot} , Mode Size (with a high FOM) are some finer parameters that have been shown to help design the waveguide proficiently.

We are anticipating the need to do a similar analysis on the materials we find and select for our waveguides.

The National Academy of Sciences Senior Associateship administered by NRC/AFOSR

Based on the work done during the summer fellowships of 2002 and 2003 followed by this extension grant, an application was made for such a fellowship which has now been awarded. The waveguide research will be continued together with the general research on quantum concepts such as Orbital Angular Momentum states of light and entanglement thereof during this one year period. The fellowship has been a very positive outcome of the Extension Grant.

Software search for waveguide simulation

The following pieces of software have been looked at for simulation and data acquisition and analysis purposes in this waveguide research supported by this extension grant.

LABVIEW, MATLAB/SIMULINK, FEMLAB.

A one-day seminar on LABVIEW 7.1 has been attended already and a three-day workshop will be attended on FEMLAB during the fellowship.

Future Work

The year long research associateship will help to continue the design, fabrication, and testing of polymer slab waveguides for further research possibilities in the field of quantum information processing as desired.

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